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FINAL REPORT ON TECHNOLOGY DEMONSTRATION OF SINGLE HYDRAULIC FLUID FOR ARMORED GROUND VEHICLE SYSTEMS

INTERIM REPORT
TFLRF No. 306

By

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13. ABSTRACT (Maximum 200 words)

The primary hydraulic fluids used today by the U.S. Army are MIL-H-6083, MIL-H-46170, and MIL-H-5606. MIL-H-6083 is a petroleum-based, low flash point hydraulic fluid, and MIL-H-46170 is a synthetic-based hydraulic fluid with a higher flash point but extremely high viscosity at lower temperatures. MIL-H-5606 is identical to MIL-H-6083 with the exception of the corrosion inhibition qualities of the latter. A new fluid, referred to as single hydraulic fluid (SHF), is synthetic-based with improved low-temperature viscosity characteristics and fire resistance comparable to MIL-H-46170. SHF characteristics, laboratory evaluations, and field demonstration preliminary results were reported in Interim Report BFLRF No. 298, entitled "Technology Demonstration of Single Hydraulic Fluid for Armored Ground Vehicle Systems." The present report incorporates the field demonstration preliminary results found in the aforementioned report and results of field demonstrations conducted through December 1994.

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EXECUTIVE SUMMARY

<u>**Problems:**</u> The primary hydraulic fluids currently used by the U.S. Army are MIL-H-6083, MIL-H-46170, and MIL-H-5606. MIL-H-46170 was developed in the 1970's as a replacement for MIL-H-6083, which was considerably more flammable. However, since MIL-H-46170 is much more viscous at –40°C, certain applications required the continued use of MIL-H-6083 (e.g., the M-109 self-propelled howitzers). MIL-H-5606, although intended for aircraft, continues to be required for some vehicles.

<u>**Objective:**</u> The objective of this project was to measure the performance of single hydraulic fluid (SHF) relative to the performance of petroleum-based MIL-H-6083 and MIL-H-5606 and synthetic-based MIL-H-46170 fluids.

<u>**Importance of Project:**</u> This program will provide the U.S. Army operational testing data which can be used to reduce the amount of additional testing required by the user for adoption to SHF. SHF will provide an alternative hydraulic fluid, known as single hydraulic fluid, that has better low-temperature properties than MIL-H-46170 and is less flammable than MIL-H-6083 or MIL-H-5606. A secondary benefit is that hydraulic fluid inventory can be reduced from three fluids to one fluid, eliminating the possibility of putting the wrong hydraulic fluid in certain vehicles and reducing the logistics burden.

<u>**Technical Approach:**</u> The performance of six M109A2 howitzers and six M1A1 tanks filled with SHF was measured against the performance of like vehicles filled with conventional MIL-H-6083 and MIL-H-46170 fluids. Monitoring included quarterly sampling of the hydraulic fluid, timed performance function evaluations of hydraulic systems, and observations of live fire exercises on a side-by-side comparison.

<u>**Accomplishments:**</u> Chemical analyses were conducted on the new fluid (i.e., SHF) and the fluid samples taken at time of changeover to the new fluid. Results were generally within the requirements for each respective fluid. There were no differences noted in hydraulic system function tests or during live fire exercises. Dynamic seal seepage observed during the middle of the demonstration corrected itself by the end of the program.

<u>**Military Impact:**</u> It is expected that this demonstration will provide the U.S. Army with an acceptable replacement for three currently used hydraulic fluids, improving the shortcomings of each.

FOREWORD/ACKNOWLEDGMENTS

This work was performed by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas, during the period October 1992 through December 1994 under Contract No. DAAK70-92-C-0059. The work was funded by the U.S. Army TARDEC, Mobility Technology Center–Belvoir (MTCB), Ft. Belvoir, Virginia. Mr. T.C. Bowen (AMSTA-RBFF) of MTCB served as contracting officer's representative, and Ms. Ellen Purdy (AMSTA-FLH), Mr. Al Rasberry (AMSTA-FLF), and Mr. M.E. LePera (AMSTA-RBF) of MTCB served as technical monitors.

This field demonstration was conducted at Ft. Bliss, Texas, with the assistance and cooperation of members from 1st and 2nd Howitzer Batteries, and D and H Companies of the 1st and 2nd Squadrons, 3rd Armored Cavalry Regiment (ACR). Special mention is given to Messrs. Everett Coppock and Fernando Rivera, Jr., of the Supply and Services Division bulk petroleum, oil, and lubricant (POL) facility located at Ft. Bliss, Texas, for the logistical support rendered throughout the program and to SGT Donna Rutkowski (AMSTA-FLH) of MTCB for her assistance during the initial fluid changeover.

The authors appreciate the contributions of the following TFLRF staff: Ms. Lona A. McInnis for serving as technical liaison; Messrs. Douglas M. Yost, William E. Likos, and Sidney J. Lestz for providing engineering support; and Ms. Mary M. Clark for editing and report preparation.

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I. INTRODUCTION

The Army currently requires three separate military specification hydraulic fluids for ground vehicles and equipment systems. MIL-H-46170 (1)*, designated FRH, is a fire resistant, corrosion inhibited, synthetic-based hydraulic fluid with a low temperature operability deficiency at temperatures below –40°C. MIL-H-6083 (2), designated OHT, is a corrosion inhibited, petroleum-based hydraulic fluid with poor fire resistant qualities but excellent low temperature operability down to –54°C. MIL-H-5606 (3), designated OHA, is identical to OHT but does not have any corrosion inhibition qualities.

The MIL-H-46170 fluid is used in all armored vehicles that constitute the Abrams fleet and its derivatives (e.g., the Armored Vehicle Launcher Bridge, the M88 retriever, etc). MIL-H-46170 is not used in any self-propelled artillery exclusively using MIL-H-6083. The MIL-H-5606 fluid, which was intended primarily for aviation systems, continues to be required for some ground materiel although **it is not authorized for use in any ground materiel.** A tabulated listing obtained from individual vehicle/equipment lubrication orders identifies the current requirement for these three fluids within the Army's ground vehicle/equipment fleet (see Appendix A).

The Army (and Marine Corps), in using these three fluids, have been required to cope with low temperature operability problems; leakage due to inadequate swelling of elastomer seals; the logistical burden in stocking and using the three different fluids; the hazardous waste disposal problems associated with the three fluids; and most importantly, increased vulnerability to fire with continued use of MIL-H-6083 and MIL-H-5606, which impacts both vehicle and crew survivability. The development of a new single fluid capable of replacing MIL-H-46170, MIL-H-6083, and MIL-H-5606 would be highly beneficial and cost effective from a logistical, operational, and safety standpoint.

* Underscored numbers in parentheses refer to the list of references at the end of this report.

II. APPROACH

This technology demonstration was designed to evaluate the single hydraulic fluid (SHF) and was conducted in two phases. Phase I consisted of laboratory analyses of candidate fluids formulated against a series of performance requirements, while Phase II involved a field demonstration of the selected fluid in actual combat equipment.

Liaison/coordination meetings were held with personnel from the Directorate of Industrial Support (DIS); the U.S. Army Tank-Automotive Research, Development and Engineering Center (TARDEC); and the former U.S. Army Munitions, Armament and Chemical Command, which is now part of the U.S. Army Tank-automotive and Armaments Command (TACOM); logistics assistance representatives (LAR's); and 3rd Armored Cavalry Regiment (ACR) to insure a smooth implementation of the demonstration program. A SHF pilot field demonstration plan for Ft. Bliss, Texas (Appendix B), was staffed through the U.S. Army TARDEC Mobility Technology Center-Belvoir (MTCB), Ft. Belvoir, Virginia, and the Command Staff and Regimental Maintenance Management Center of the 3rd ACR at Ft. Bliss, Texas. Copies of the field demonstration plan were provided to the Deputy Director for Logistics, DIS, and the U.S. Army Materiel Command Logistics Assistance office at Ft. Bliss, Texas. The command staff of the 3rd ACR approved the field demonstration plan and tasked the 1st and 2nd Squadrons to support the demonstration program (Appendix C). Fluid conversion was planned in the M1A1 Main Battle Tank, the M3A2 Cavalry Fighting Vehicle, and the M109A2 Self-Propelled Howitzer combat vehicle. The M3A2 fighting vehicle was later omitted because the only hydraulic actuated component is the rear ramp door which, if necessary, can be opened and closed manually.

III. OBJECTIVE

The objective of this demonstration was to measure the performance of SHF relative to the performance of petroleum-based MIL-H-6083 and synthetic-based MIL-H-46170 fluids. The performance was measured by monitoring the following:

- Selected test vehicles operating on SHF and selected control vehicles operating on their required hydraulic fluid;

- Hours of operation and live rounds fired from both test and control vehicles;

- System performance inspections as specified in applicable technical manuals;

- Results of periodic hydraulic fluid sampling analysis.

IV. DETAILS OF DEMONSTRATION

A. General

The hydraulic fluids used in this program are shown in TABLE 1. Key properties are summarized and compared to specification requirements. Laboratory testing was conducted on candidate SHF samples from different suppliers (Appendix D). The fluid sample which more closely approximated the proposed SHF requirements was selected to conduct the field demonstration and is shown in TABLE 1. Analytical procedures performed on these two candidate fluids included flammability testing, flash point, fire point, autoignition, temperature, flame propagation, hot surface ignition, and high pressure spray ignition. Ballistic testing, oxidation-corrosion stability, wear testing, and hydraulic pump endurance testing were also conducted. Results and discussion of laboratory testing were reported previously in Interim Report BFLRF No. 298 (4) where discrepancies in "proposed" and "measured" properties were noted. The aforementioned report also covered results of field evaluations through December 1993; therefore, for the sake of clarity and cohesiveness, this report will include previous findings.

TABLE 1. Properties of Fluids Used in Technology Demonstration

Properties	SHF (Proposed)	Analysis Results: SHF	MIL-H-46170	MIL-H-6083
Pour Point, D 97*, °C	–60 min.	–54	<–56	<–60
Viscosity, D 445†, cSt				
40°C	8 min.	9.3	15.8	13.70
100°C	2.5 min.	2.7	3.8	4.6
–40°C	800 max.	744	2,550	715
Acid Number, D 664‡, mg KOH/g	Report	0.22	0.14	0.14
Flash Point, D 92§, °C	180 min.	166	224	110
Fire Point, D 92, °C	190 min.	200	252	121
Water Content, D 1744♦, wt%	0.01 max.	0.02	0.05	0.03

* ASTM D 97 procedure can be found in Reference 5.
† ASTM D 445 procedure can be found in Reference 6.
‡ ASTM D 664 procedure can be found in Reference 7.
§ ASTM D 92 procedure can be found in Reference 8.
♦ ASTM D 1744 procedure can be found in Reference 9.

B. Test Vehicles

The test vehicles were selected by local organizations tasked to support the field demonstration. Six M109A2 Howitzers and six M1A1 tanks were selected by both the 1st and 2nd Squadrons of the 3rd ACR. Of the 24 vehicles selected, three vehicles of each kind from each unit (for a total of twelve) were designated as control test vehicles for comparison. The hydraulic systems on the vehicles were checked for proper operation and leaks. The vehicles participating in the SHF demonstration program are given in TABLE 2 and shown in Figs. 1 and 2.

C. Test Hydraulic Fluid

The SHF used in the test vehicles was purchased from Huls America, Inc. and supplied to Ft. Bliss by the U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) located at Southwest Research Institute (SwRI), San Antonio, Texas. The MIL-H-6083 and MIL-H-46170 fluids used in the control vehicles were obtained through Army supply channels. The SHF

proposed requirements and the MIL-H-46170 and MIL-H-6083 requirements are given in TABLE 3.

TABLE 2. 3rd ACR Vehicles Participating in the MIL-H-46170 Single Hydraulic Fluid (SHF) Demonstration Program at Ft. Bliss, Texas

Vehicle No.	Vehicle Type	Serial No.	Test (T), Control (C)	Miles	Hours	Unit	In-Program Date
HOW-12	M109A2	5324	T	567	78	2nd Sqd.	28 Jun 93
HOW-15	M109A2	2893	T	5,322	52	2nd Sqd.	30 Jun 93
HOW-16	M109A2	2132	T	2,822	199	2nd Sqd.	01 Jul 93
HOW-13	M109A2	5030	C	1,667	175	2nd Sqd.	30 Oct 93
HOW-11	M109A2	4340	C	2,594	126	2nd Sqd.	30 Oct 93
HOW-14	M109A2	4950	C	2,444	132	2nd Sqd.	30 Oct 93
H-13	M1A1	L12523	T	841	173	2nd Sqd.	07 Jul 93
H-23	M1A1	L13011	T	797	163	2nd Sqd.	07 Jul 93
H-33	M1A1	L13021	T	897	167	2nd Sqd.	07 Jul 93
H-12	M1A1	L12527	C	792	174	2nd Sqd.	07 Jul 93
H-22	M1A1	L13028	C	847	198	2nd Sqd.	08 Jul 93
H-32	M1A1	L13009	C	956	184	2nd Sqd.	08 Jul 93
HOW-11	M109A2	4910	T	2,995	296	1st Sqd.	10 Aug 93
HOW-12	M109A2	4887	T	1,837	325	1st Sqd.	11 Aug 93
HOW-13	M109A2	2895	T	1,821	376	1st Sqd.	11 Aug 93
HOW-14	M109A2	5477	C	851	100	1st Sqd.	13 Aug 93
HOW-15	M109A2	4907	C	3,739	356	1st Sqd.	13 Aug 93
HOW-16	M109A2	2899	C	4,361	351	1st Sqd.	12 Aug 93
D-14	M1A1	L13071	T	1,063	159	1st Sqd.	16 Aug 93
D-24	M1A1	L13045	T	1,086	177	1st Sqd.	17 Aug 93
D-34	M1A1	L13073	T	1,376	790	1st Sqd.	18 Aug 93
D-12	M1A1	L13062	C	1,247	191	1st Sqd.	16 Aug 93
D-22	M1A1	L13075	C	1,104	181	1st Sqd.	18 Aug 93
D-32	M1A1	L13037	C	1,190	187	1st Sqd.	17 Aug 93

Figure 1. An M109A2 Howitzer

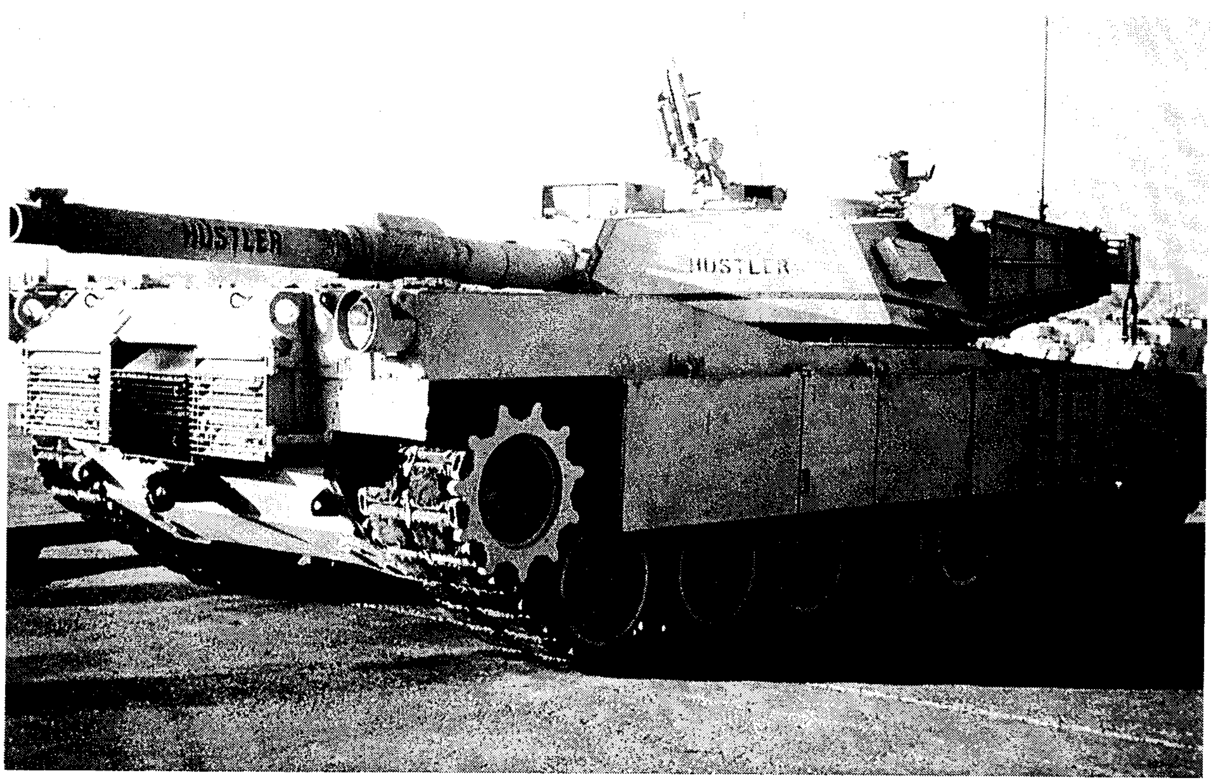

Figure 2. An M1A1 tank

TABLE 3. Test Hydraulic Fluid Requirements

Properties	SHF (Proposed)	MIL-H-46170	MIL-H-6083
Pour Point, D 97, °C	–60 min.	–54 min.	–59 min.
Viscosity, D 445, cSt			
40°C	8 min.	19.5 max.	13 min.
100°C	2.5 min.	3.4 min.	NR*
–40°C	800 max.	2,600 max.	800 max.
Acid Number, D 664, mg KOH/g	Report	0.20 max.	0.20 max.
Flash Point, D 92, °C	180 min.	204 min.	82 min.
Fire Point, D 92, °C	190 min.	246 max.	NR
Water Content, D 1744, wt%	0.01 max.	0.05 max.	0.05 max.

* NR = Not required

D. Fluid Conversion Methodology

1. M109A2 Self-Propelled Howitzers

The vehicles were warmed to normal operating temperature and the hydraulic systems exercised. The hydraulic systems were then depressurized and the fluid drained from reservoirs, cylinders, and main gun recoil mechanisms by disconnecting selected hydraulic lines as specified in Technical Manual (TM) 9-2350-303-20. Reservoirs, hydraulic cylinders, and lines were thoroughly purged and bled; however, there was no guarantee that all hydraulic fluid could be removed due to the geometry of these systems. The hydraulic systems were then filled with SHF and pressurized. The vehicles were again warmed to normal operating temperature and the hydraulic systems exercised. The drain process was repeated a second time to flush the systems as thoroughly as possible of MIL-H-6083 fluid. After the final fill, main gun recuperator pin adjustments were performed as specified in the TM. No components or seals were changed during the conversion procedure.

2. M1A1 Main Battle Tanks

The vehicles were warmed to normal operating temperature and the hydraulic systems exercised. The systems were depressurized and the hydraulic fluid drained from the main reservoir by disconnecting the hydraulic line, which supplies fluid to the ammunition door actuator, and using the on-board auxiliary pump to drain the fluid. The fluid in the main gun recoil mechanism was drained by removing the drain plug at the bottom of the recoil reservoir. The hydraulic systems were then filled with SHF and pressurized. The vehicles were again warmed to normal operating temperature and the hydraulic systems exercised. The drain process was repeated to flush the systems as thoroughly as possible of MIL-H-46170 fluid; however, the same problem in completely purging the systems of residual MIL-H-46170 applied here as well.

E. Fleet Monitoring

TFLRF personnel visited the 1st and 2nd Squadrons on a quarterly basis to monitor the progress of test and control vehicles. In addition to operational data collection, visual inspection of the equipment, and solicitation of comments from vehicle crews, timed tests and sample analyses were also performed.

1. Timed Hydraulic System Function Tests

Timed hydraulic system function tests were conducted on the test and control vehicles to evaluate differences between MIL-H-46170, MIL-H-6083, and SHF. Main gun elevations and 360° turret rotations were timed (in seconds) in both directions. Three timed measurements were recorded and averaged for each function. These tests were performed before and after the SHF conversion and every quarter thereafter. The main gun elevations on the M1A1 tank occurred so quickly (less than one second using MIL-H-46170 or SHF) that after the second quarter, a modified boresight test to inspect for main gun drift was performed in lieu of the gun elevation test. Additionally, on the M109A2 control vehicles, timed tests were performed before and after each hydraulic system's fluid bleed, purge, and main gun recuperator pin adjustment.

2. Hydraulic Fluid Sampling and Analysis

A comprehensive sampling and analysis program was conducted on a quarterly basis throughout the demonstration. Samples were obtained from the M1A1 and M109A2 test vehicles before the changeover to SHF, after the changeover to SHF, and on a quarterly basis. Final samples were obtained after the vehicles were changed back to the original hydraulic fluid. Samples were obtained from the control vehicles at the beginning of the program and quarterly thereafter to insure conformity to specification. The analysis protocol shown in TABLE 4 was coordinated with MTCB.

TABLE 4. Hydraulic Fluid Analysis Protocol

Pour Point, D 97, °C
Viscosity, D 445, cSt
40°C
100°C
–40°C
Acid Number, D 664, mg KOH/g
Flash Point, D 92, °C
Fire Point, D 92, °C
Water Content, D 1744, wt%

V. RESULTS OF DEMONSTRATION

A. Hydraulic System Function Tests

1. M109A2

The timed hydraulic system function tests performed on the M109A2 howitzer test and control vehicles are shown in TABLES 5, 6, and 7. There were no differences noted in the performances of the hydraulic systems in the test and control vehicles. There was a noted improvement in main gun elevation after fluid changeover and/or purge in test and control vehicles. During the purge cycle, the equilibrator is bled and purged of air. The system is considered equilibrated when the time to fully elevate and lower the main gun is approximately the same. However, as can be seen in TABLES 5 through 7, gun elevation times fluctuated considerably throughout the program in both test and control vehicles. Main gun equilibration is performed by the crews quite frequently. Also, TABLE 7 shows timed function test results for three howitzers:

TABLE 5. Timed Function Test Results of 1st Squadron M109A2 Howitzer Test Vehicles

	Average Time, s, to:					
	Elevation (max.)		Rotation (360°)			
How/1-11 SN 4910	Up	Down	c.w.*	c.c.w.†	Test Date	Approx. Temp., °C
Before changeover to SHF	18.45	12.06	22.97	23.67	10 Aug 93	36
After changeover to SHF	16.04	12.39	20.88	20.78	10 Aug 93	36
1st Quarter	16.63	10.36	23.19	25.14	30 Nov 93	16
2nd Quarter	14.51	7.54	21.47	21.32	17 Mar 94	11
3rd Quarter	14.05	7.28	20.92	20.69	06 Jul 94	37
4th Quarter	14.87	7.16	21.86	21.84	27 Sep 94	32
After chgovr back to MIL-H-6083	13.89	19.30	21.62	21.57	27 Sep 94	32
How/1-12 SN 4887						
Before changeover to SHF	15.36	12.18	24.60	23.31	11 Aug 93	36
After changeover to SHF	12.16	12.69	23.22	23.39	11 Aug 93	36
1st Quarter	15.97	11.24	24.05	24.09	30 Nov 93	16
2nd Quarter	13.79	12.09	24.05	25.36	14 Mar 94	11
3rd Quarter	12.95	12.16	23.43	23.19	06 Jul 94	37
4th Quarter	14.31	11.31	22.86	22.83	28 Sep 94	32
After chgovr back to MIL-H-6083	11.96	14.19	23.19	23.20	28 Sep 94	32
How/1-13 SN 2895						
Before changeover to SHF	20.86	12.24	23.20	22.67	11 Aug 93	36
After changeover to SHF	15.22	12.81	21.57	21.25	11 Aug 93	36
1st Quarter	15.11	14.43	22.05	22.09	30 Nov 93	16
2nd Quarter	15.27	13.95	22.36	22.09	14 Mar 93	11
3rd Quarter	13.88	21.71	21.93	21.98	06 Jul 93	37
4th Quarter	14.18	16.43	22.85	22.63	28 Sep 93	32
After chgovr back to MIL-H-6083	15.01	20.82	22.85	22.63	28 Sep 93	32

* c.w. = Clockwise

† c.c.w. = Counterclockwise

TABLE 6. Timed Function Test Results of 2nd Squadron M109A2 Howitzer Test Vehicles

	Average Time, s, to:					
	Elevation (max.)		Rotation (360°)			
	Up	Down	c.w.*	c.c.w.†	Test Date	Approx. Temp., °C
How/2-12 SN 5324						
Before changeover to SHF	15.38	14.72	22.24	22.00	28 Jun 93	38
After changeover to SHF	15.31	12.37	22.39	21.09	28 Jun 93	38
1st Quarter	21.09	10.82	23.05	22.58	29 Nov 93	16
2nd Quarter	N/A§	N/A	N/A	N/A		
3rd Quarter	13.21	11.19	21.04	20.77	07 Jul 94	37
4th Quarter	13.92	11.40	20.81	21.00	19 Sep 94	33
After chgovr back to MIL-H-6083	12.84	13.29	22.20	22.16	19 Sep 94	33
How/2-15 SN 2893						
Before changeover to SHF	16.81	31.98	23.00	22.62	30 Jun 93	38
After changeover to SHF	16.52	12.60	21.75	21.24	30 Jun 93	38
1st Quarter	19.57	12.69	22.56	22.19	29 Nov 93	16
2nd Quarter	N/A	N/A	N/A	N/A		
3rd Quarter	14.09	21.29	21.86	21.11	07 Jul 94	37
4th Quarter	15.14	18.43	21.56	21.93	19 Sep 94	33
After chgovr back to MIL-H-6083	14.37	13.84	21.95	21.80	19 Sep 94	33
How/2-16 SN 2132						
Before changeover to SHF	28.61	10.71	25.27	25.22	01 Jul 93	38
After changeover to SHF	17.48	12.03	24.05	24.25	01 Jul 93	38
1st Quarter	N/A	N/A	N/A	N/A		
2nd Quarter	16.78	11.58	26.56	26.33	02 Mar 94	11
3rd Quarter	16.03	12.44	N/A	N/A	07 Jul 94	38
4th Quarter	18.54	13.46	N/A	N/A	20 Sep 94	33
After chgovr back to MIL-H-6083	16.34	13.98	N/A	N/A	20 Sep 94	33

* c.w. = Clockwise
† c.c.w. = Counterclockwise
§ N/A = Not available for testing

TABLE 7. Timed Function Test Results of 1st and 2nd Squadron M109A2 Howitzer Control Vehicles

	Average Time, s, to:					
	Elevation (max.)		Rotation (360°)			
	Up	Down	c.w.*	c.c.w.†	Test Date	Approx. Temp., °C
1st Squadron						
How/1-15 SN 4907						
Initial Testing	16.42	13.51	25.03	25.09	12 Aug 94	36
After Purge	N/A§	N/A	N/A	N/A		
1st Quarter	16.06	14.23	24.22	23.61	01 Dec 93	16
2nd Quarter	17.50	12.87	24.59	23.96	14 Mar 94	11
3rd Quarter	13.77	16.35	22.20	21.71	06 Jul 94	37
4th Quarter	15.93	14.24	24.01	23.59	29 Sep 94	32
How/1-16 SN 2899						
Initial Testing	15.29	14.62	22.66	22.57	13 Aug 93	36
After Purge	15.01	13.97	22.24	22.44	13 Aug 93	36
1st Quarter	19.77	12.84	24.88	24.66	30 Nov 93	16
2nd Quarter	18.16	12.83	24.14	24.77	14 Mar 93	11
3rd Quarter	15.22	12.43	23.17	23.15	06 Jul 93	37
4th Quarter	14.20	15.39	22.48	22.91	29 Sep 93	32
2nd Squadron						
How/2-13 SN 5030						
Initial Testing	15.36	10.65	21.63	21.36	13 Aug 93	36
After Purge	12.85	12.81	21.79	21.54	13 Aug 93	36
1st Quarter	17.90	11.50	23.75	23.43	29 Nov 93	16
2nd Quarter	17.33	11.30	24.24	23.18	04 Mar 93	11
3rd Quarter	17.50	21.70	21.70	21.55	07 Jul 93	37
4th Quarter	N/A	N/A	N/A	N/A		

* c.w. = Clockwise
† c.c.w. = Counterclockwise
§ N/A = Not available for testing

two from the 1st Squadron (How/1-15 and How/1-16) and one from the 2nd Squadron (How/2-13). The reason for only three control vehicles instead of six is that during the initial visit and for the next two subsequent quarterly visits, the hydraulic systems in vehicles How/1-14, How/2-11, and How/2-14 were not operating properly. Hydraulic function testing on these vehicles was thereafter discontinued. This is not to say that the vehicles were inoperable throughout this period of time. The vehicles continued to be deployed to field exercises and participate in live fire missions. TFLRF staff continued to monitor these vehicles for total miles/hours operated and live rounds fired.

2. M1A1

TABLES 8 through 11 show the results of main gun elevation and turret rotation for the test and control M1A1 vehicles. There were no differences noted between the performances of the hydraulic systems in tanks filled with SHF and MIL-H-46170 fluid. After the second quarter testing, a modified boresighting procedure utilizing the M27A1 boresighting device was used to test the elevation mechanism. The tanks were started and hydraulic systems exercised and purged. The M27A1 boresighting device was installed in the main gun. A target was sighted at approximately 1,200 meters, and utilizing a G pattern target approach to minimize drift, the boresight horizontal reticle was aligned level with the horizontal plane of the target. The fire control was set in the emergency mode, and five minutes were allowed to elapse. The target sighting was again checked to determine variance from original sighting. The test and control vehicles collectively experienced some degree of gun droop, as can be seen in TABLES 12 and 13.

B. Live Fire Exercises

All test vehicles converted to SHF underwent live fire exercises. 1st Howitzer Battery, 1/3 ACR, 2nd Howitzer Battery, and H Company, 2/3 ACR conducted live firing at Dona Ana Range, New Mexico during several field and tank gunnery exercises. D Company, 1/3 ACR conducted live

TABLE 8. Timed Function Test Results of 1st Squadron M1A1 Abrams Tank Test Vehicles

	Average Time, s, to:					
	Elevation (max.)		Rotation (360°)			
D/1-14 SN L13071	Up	Down	c.w.*	c.c.w.†	Test Date	Approx. Temp., °C
Before changeover to SHF	0.67	0.71	9.94	9.47	16 Aug 93	36
After changeover to SHF	0.81	0.67	9.42	9.30	16 Aug 93	36
1st Quarter	0.72	0.65	9.78	9.67	30 Nov 93	16
2nd Quarter	0.64	0.55	9.41	9.31	14 Mar 94	11
3rd Quarter	N/A§	N/A	9.32	9.37	08 Jul 94	37
4th Quarter	N/A	N/A	9.57	9.42	04 Oct 94	16
After chgovr back to MIL-H-46170	N/A	N/A	9.51	9.48	04 Oct 94	16
D/1-24 SN L13045						
Before changeover to SHF	0.75	0.62	9.65	9.43	17 Aug 93	36
After changeover to SHF	0.73	0.68	9.36	9.40	17 Aug 93	36
1st Quarter	0.64	0.57	9.94	9.67	30 Nov 93	16
2nd Quarter	0.65	0.54	9.74	9.43	14 Mar 94	11
3rd Quarter	N/A	N/A	9.54	9.32	06 Jul 94	37
4th Quarter	N/A	N/A	9.61	9.47	04 Oct 94	16
After chgovr back to MIL-H-46170	N/A	N/A	9.67	9.60	04 Oct 94	16
D/1-34 SN L13073						
Before changeover to SHF	0.70	0.65	9.60	9.56	18 Aug 93	36
After changeover to SHF	0.74	0.66	9.30	9.40	18 Aug 93	36
1st Quarter	0.73	0.61	10.43	9.89	30 Nov 93	16
2nd Quarter	0.72	0.64	9.60	9.50	14 Mar 94	11
3rd Quarter	N/A	N/A	9.30	9.30	06 Jul 94	37
4th Quarter	N/A	N/A	9.60	9.44	05 Oct 94	16
After chgovr back to MIL-H-46170	N/A	N/A	9.34	9.42	05 Oct 94	16

* c.w. = Clockwise
† c.c.w. = Counterclockwise
§ N/A = Not applicable

TABLE 9. Timed Function Test Results of 2nd Squadron M1A1 Abrams Tank Test Vehicles

	Average Time, s, to:					
	Elevation (max.)		Rotation (360°)			
H/2-13 SN L12523	Up	Down	c.w.*	c.c.w.†	Test Date	Approx. Temp., °C
Before changeover to SHF	0.86	0.43	9.79	9.72	07 Jul 93	37
After changeover to SHF	0.68	0.63	9.67	9.38	07 Jul 93	37
1st Quarter	0.79	0.55	9.71	9.74	01 Dec 93	16
2nd Quarter	0.78	0.72	9.56	9.96	04 Mar 94	11
3rd Quarter	N/A§	N/A	9.61	9.25	05 Jul 94	37
4th Quarter	N/A	N/A	9.63	9.44	18 Oct 94	18
After chgovr back to MIL-H-46170	N/A	N/A	9.72	9.52	18 Oct 94	18
H/2-23 SN L13011						
Before changeover to SHF	0.78	0.80	9.63	9.53	08 Jul 93	37
After changeover to SHF	0.88	0.76	9.59	9.42	08 Jul 93	37
1st Quarter	0.73	0.68	9.77	9.47	01 Dec 93	16
2nd Quarter	0.82	0.73	10.05	9.97	02 Mar 94	11
3rd Quarter	N/A	N/A	9.54	9.23	05 Jul 94	37
4th Quarter	N/A	N/A	9.78	9.53	18 Oct 94	18
After chgovr back to MIL-H-46170	N/A	N/A	9.12	9.59	19 Oct 94	18
H/2-33 SN L13021						
Before changeover to SHF	1.23	0.79	9.78	9.69	08 Jul 93	37
After changeover to SHF	0.79	0.70	9.45	9.36	08 Jul 93	37
1st Quarter	0.70	0.65	9.92	9.60	01 Dec 93	16
2nd Quarter	0.73	0.65	9.74	9.49	02 Mar 94	11
3rd Quarter	N/A	N/A	9.64	9.64	05 Jul 94	37
4th Quarter	N/A	N/A	9.42	9.48	18 Oct 94	18
After chgovr back to MIL-H-46170	N/A	N/A	9.51	9.70	18 Oct 94	18

* c.w. = Clockwise

† c.c.w. = Counterclockwise

§ N/A = Not applicable

TABLE 10. Timed Function Test Results of 1st Squadron Abrams Tank Control Vehicles

	Average Time, s, to:					
	Elevation (max.)		Rotation (360°)			
D/1-12 SN L13062	Up	Down	c.w.*	c.c.w.†	Test Date	Approx. Temp., °C
Initial Testing	0.82	0.75	9.82	9.59	16 Aug 93	37
1st Quarter	0.78	0.65	10.29	10.05	30 Nov 93	16
2nd Quarter	0.62	0.53	10.08	9.90	14 Mar 94	11
3rd Quarter	N/A§	N/A	9.86	9.75	08 Jul 94	37
4th Quarter	N/A	N/A	9.82	9.76	05 Oct 94	18
D/1-22 SN L13075						
Initial Testing	0.84	0.68	9.88	9.87	18 Aug 93	37
1st Quarter	0.67	0.61	10.49	10.33	30 Nov 93	16
2nd Quarter	0.76	0.65	10.04	9.97	14 Mar 94	11
3rd Quarter	N/A	N/A	9.82	9.80	06 Jul 94	37
4th Quarter	N/A	N/A	9.98	9.88	05 Oct 94	18
D/1-32 SN L13037						
Initial Testing	0.77	0.59	9.63	9.53	17 Aug 93	37
1st Quarter	0.76	0.64	10.00	10.00	30 Nov 93	16
2nd Quarter	0.67	0.60	9.51	9.56	14 Mar 94	11
3rd Quarter	N/A	N/A	9.29	9.44	06 Jul 94	37
4th Quarter	N/A	N/A	9.48	9.50	05 Oct 94	18

* c.w. = Clockwise
† c.c.w. = Counterclockwise
§ N/A = Not applicable

firing at Dona Ana Range and at the National Training Center (NTC) at Ft. Irwin, California during annual training exercises. The howitzers fired an assortment of high explosive (HE) and illumination rounds while the tanks fired a combination of target practice SABOT and high explosive antitank (HEAT) rounds. TFLRF personnel were present during live fire exercises at Dona Ana Range and at NTC. After the live fire exercises, howitzer and tank crews were interviewed on the performance of the hydraulic systems, i.e., turret rotation, main gun elevation

TABLE 11. Timed Function Test Results of 2nd Squadron Abrams Tank Control Vehicles

H/2-12 SN L12527	Average Time, s, to: Elevation (max.) Up	Down	Rotation (360°) c.w.*	c.c.w.†	Test Date	Approx. Temp., °C
Initial Testing	1.05	0.88	9.53	11.23	07 Jul 93	37
1st Quarter	0.74	0.67	10.02	9.93	01 Dec 93	16
2nd Quarter	0.73	0.70	9.99	9.97	04 Mar 93	11
3rd Quarter	N/A§	N/A	9.87	10.30	05 Jul 93	37
4th Quarter	N/A	N/A	9.92	10.09	18 Oct 94	18
H/2-22 SN L13028						
Initial Testing	0.97	0.98	10.24	9.44	07 Jul 93	37
1st Quarter	0.70	0.62	10.11	9.98	01 Dec 93	16
2nd Quarter	0.77	0.58	10.15	10.13	02 Mar 94	11
3rd Quarter	N/A	N/A	9.74	9.57	05 Jul 93	37
4th Quarter	N/A	N/A	9.73	9.45	18 Oct 93	18
H/2-32 SN L13009						
Initial Testing	1.07	0.75	9.59	9.38	07 Jul 93	37
1st Quarter	0.62	0.61	9.94	9.67	01 Dec 93	16
2nd Quarter	0.72	0.65	10.07	9.51	02 Mar 94	11
3rd Quarter	N/A	N/A	9.52	9.24	05 Jul 94	37
4th Quarter	N/A	N/A	9.42	9.38	18 Oct 94	18

* c.w. = Clockwise
† c.c.w. = Counterclockwise
§ N/A = Not applicable

and recoil function, ammunition door operation, and moving target tracking (M1A1). No differences between OHT, FRH, and SHF fluids were reported or observed. TABLES 14 and 15 show the total number and type of rounds fired and miles/kilometers and hours accumulated by M109A2 and M1A1 test and control vehicles.

TABLE 12. Boresighting Results of Control M1A1 Tanks Assigned to D and H Companies, 1st and 2nd Squadrons, 3rd ACR

Tank No.	Initial Testing*	Test Date	Approx. Temp., °C	3rd Quarter Testing*	Test Date	Approx. Temp., °C	4th Quarter Testing*	Test Date	Approx. Temp., °C
D-12	0	05 May 94	37	0.10	08 Jul 94	37	0.10	05 Oct 94	16
D-22	0.10	05 May 94	37	0.10	06 Jul 94	37	0	05 Oct 94	16
D-32	0.07	05 May 94	37	0.30	06 Jul 94	37	0.10	05 Oct 94	16
H-12	0	05 Apr 94	37	N/D†	--	--	0.40	18 Oct 94	18
H-22	N/D	--	--	0.25	05 Jul 94	37	0.25	18 Oct 94	18
H-32	N/D	--	--	0.25	05 Jul 94	37	0.25	18 Oct 94	18

* Drop in mils (5 min)
† ND = Not determined

TABLE 13. Boresighting Results of Test M1A1 Tanks Assigned to D and H Companies, 1st and 2nd Squadrons, 3rd ACR

Tank No.	Initial Testing*	Test Date	Approx. Temp., °C	3rd Quarter Testing*	Test Date	Approx. Temp., °C	4th Quarter Testing*	After Changeover Testing*†	Test Date	Approx. Temp., °C
D-14	0.30	05 May 94	33	0.50	08 Jul 94	37	0.40	0.40	04 Oct 94	16
D-24	0.10	06 May 94	33	0.50	06 Jul 94	37	0.30	0.30	04 Oct 94	16
D-34	0.25	06 May 94	33	0.10	06 Jul 94	37	0.10	0.25	05 Oct 94	16
H-13	0.75	05 Apr 94	26	0.30	05 Jul 94	37	0.20	0.10	18 Oct 94	18
H-23	0.25	05 Apr 94	26	0.20	05 Jul 94	37	0.25	0.20	19 Oct 94	18
H-33	0.25	05 Apr 94	26	0.90	05 Jul 94	37	0.10	0.30	19 Oct 94	18

* Drop in mils (5 min)
† to MIL-H-46170

TABLE 14. Total Live Rounds Fired and Miles/Hours Accumulated by M109A2 Howitzer Test and Control Vehicles

Fluid Type	Vehicle No.	Unit	Ammunition Type: HE	Ammunition Type: Illumination	Total: Miles	Total: Hours
SHF	11	1st Squadron	138	50	276	62
SHF	12	1st Squadron	150	45	283*	49
SHF	13	1st Squadron	120	34	380	45
OHT	15	1st Squadron	120	17	230	43
OHT	16	1st Squadron	138	5	258	41*
OHT	17	1st Squadron	120	16	220	45
SHF	12	2nd Squadron	148	14	580	50
SHF	15	2nd Squadron	243	18	449	53
SHF	16	2nd Squadron	249	108	450	57
OHT	11	2nd Squadron	267	33	452	50
OHT	13	2nd Squadron	365	31	329	43
OHT	14	2nd Squadron	69	10	175	25

* estimated

TABLE 15. Total Live Rounds Fired and Kilometers/Hours Accumulated by M1A1 Abrams Tank Test and Control Vehicles

Fluid Type	Vehicle No.	Unit	Ammunition Type: SABOT	Ammunition Type: HEAT	Total: Kilometers	Total: Hours
SHF	D-14	1st Squadron	100	25	646	147
SHF	D-24	1st Squadron	93	26	691	170
SHF	D-34	1st Squadron	90	28	626	176
FRH	D-12	1st Squadron	83	20	531	119
FRH	D-22	1st Squadron	92	25	593	51
FRH	D-32	1st Squadron	97	24	681	177
SHF	H-13	2nd Squadron	124	37	774	211
SHF	H-23	2nd Squadron	130	37	1,130	246
SHF	H-33	2nd Squadron	118	36	788	225
FRH	H-12	2nd Squadron	115	27	951	229
FRH	H-22	2nd Squadron	116	28	867	201
FRH	H-32	2nd Squadron	120	28	951	183

C. Sample Analysis Results

The results of the chemical analyses of the used samples are presented in Appendix E. Overall results indicate that the one-year service of the SHF did not cause the fluid chemical properties to change. These results are not unexpected since the performance of the vehicles remained fairly constant over the one-year test period.

There was some discrepancy in pour point results, but this is believed to be related to the analytical method used. The pour point of the initial sample, measured using ASTM D 97 (5), differed from the rest of the samples. A Lauda RM-6 automatic pour point analyzer was used on the remainder of the samples. Regardless of the method employed, the results were always within specification.

The viscosities at 40 and 100°C did not change appreciably throughout the year's service. Viscosities at –40°C, however, did show significant variance due to the presence of SHF (Appendix E, TABLE E-1) or FRH (TABLES E-6 and E-7). As explained earlier, due to the geometry of the hydraulic systems, it is very difficult to flush and fill without leaving some residue of the previous fluid. Replenishing the hydraulic reservoir with the improper fluid most likely was the contributing factor for the fluctuations seen in TABLE E-4. Acid number, as measured by ASTM D 664 (7), did not vary significantly, thus indicating that the base stock was chemically and thermally stable. Flash and fire points varied slightly (TABLES E-3 and E-4) due to residual OHT fluid in the systems; however, they remained within the repeatability of the ASTM D 92 (8) procedure, again verifying the stability of the base stock (by its failure to degrade into lower molecular weight materials with a lower flash point). Water content, although not a property of the base fluid, simply indicated the cleanliness of the system and the tendency of the fluid to absorb water. Although the proposed requirements are 0.01 percent water content, the problem occurs when the fluid is tested. Since the samples are shaken, any free water present will be placed in suspension and may be measured as dissolved or emulsified water. Therefore, the water content greatly depends upon the system cleanliness and dryness. In summary, there were no reported or measured problems that could be traced to chemical or thermal stability.

VI. RESOLUTIONS OF USER CONCERNS

It was the practice throughout the demonstration program to investigate all hydraulic fluid concerns of maintenance/user personnel. Two concerns surfaced during the second and third quarters of the program that warranted detailed investigation.

A. Leaking and Seeping Seals in M109A2 Vehicles

During the second quarter monitoring visit to Ft. Bliss, Texas, maintenance personnel from the 2nd Squadron reported that seals were seeping and leaking in what unit personnel considered critical components in the M109A2 vehicle, i.e., elevation, recuperator, and recoil cylinders. A thorough inspection of all test and control vehicles of both squadrons confirmed that Class I and II leaks were evident in varying degrees in the test vehicles only. A Class I leak is characterized by fluid seepage and moisture around the shaft and orifice areas. Fluid bypassing the seal in enough volume to form droplets at the shaft and orifices defines a Class II leak. Consultations to resolve the issue were held between TFLRF technical personnel, Howitzer Battery command and maintenance personnel, and AMC logistics representatives. It was noted that the end item specification for the M182 hydropneumatic gun mount used in the M109A2 howitzer, MIL-M-70821, paragraph 3.4.5, cites that for dynamic seals, immediately following cycling of the gun mount, there shall be no more than one milliliter (ml) of oil accumulation per every five (5) cycles tested at any seal interface location. Since seal leakage and seepage on the test vehicles were within the specification, they were not considered a critical factor. Also, all the hydraulic components were functioning to specification and no safety concerns were evident; therefore, the seal leaks and seepage were determined a non-issue. During the third and fourth quarter, the leaks and seepage dissipated and completely ceased by the end of the program.

B. Main Gun Drift on the M1A1 Tank

During the second quarter of the demonstration, 3rd ACR Maintenance Management Center reported to TFLRF staff that the three test tanks from H Company, 2nd Squadron had to be removed from the firing line when crews were unable to boresight the main gun due to drifting.

An investigation was started immediately to determine if the problem was fluid related. A modified boresight procedure (described earlier) was designed to check for main gun drift. This procedure, performed on all the test and control vehicles, revealed that six test and two control vehicles exhibited gun drift. As a result, the boresight procedure was performed in lieu of the gun elevation test in subsequent quarterly visits. Both the test and control vehicles exhibited varying degrees of gun drift on different occasions. In addition, the vehicles were checked for leaks and/or seepage in the servo mechanism, elevation mechanism, and manual elevation mechanism, any of which if found leaking, will cause main gun drift. An elevation mechanism in one of the test tanks was found to be leaking profusely; however, this leakage was not attributed to the SHF but rather to the introduction of a foreign object into the elevation cylinder, possibly at the time of assembly. The elevation cylinder was replaced and the drift problem abated. The specific cause for main gun drift could not be determined, although the test vehicles exhibited a greater degree of drift than the control vehicles. During interviews with tank commanders and gunners, it was concluded that slight gun drift is a common occurrence that can be nullified by adjusting various gunner controls. The experience of the crew plays a big part in the boresighting process.

C. Failed Elevation Cylinder on M1A1 Vehicle

The 2nd Squadron maintenance personnel reported that an elevation cylinder had been replaced in one of the test M1A1 tanks. The initial assessment reached by personnel of the forward maintenance support company evaluating the failed cylinder was that the SHF was deteriorating the O-rings inside the cylinder. Reportedly, the fluid that was removed from the failed cylinder was black, and pieces of elastomer were evident. TFLRF staff members, accompanied by a representative from MTCB, visited the forward support company to witness the disassembly of the elevation cylinder in an attempt to identify the origin of the problem as SHF was completely compatible with these types of elastomeric materials, indicating the deterioration observed had to be caused by other factors. It was found that the piston was severely gouged and scarred, and the O-rings were torn and tattered. The cylinder sleeve had a groove wear scar, indicating that the damage was caused by a foreign object in the hydraulic cylinder. The source of introduction of the foreign body cannot be explained since the elevation cylinder was an original part.

VII. CONCLUSIONS

The following conclusions are drawn from the SHF demonstration program at Ft. Bliss, Texas:

- There were no measurable differences in the performance of the synthetic-based SHF relative to petroleum-based MIL-H-6083 and synthetic-based MIL-H-46170 fluids.

- Dynamic seals formed minor leaks and/or seepage approximately six months after introduction into the M109 systems. However, the problem was never critical and dissipated during the third and fourth quarters, ceasing by the end of the program. This period of adjustment may be expected in vehicles using MIL-H-6083 (OHT) since the chemistry of the base fluids is different, i.e., synthetic versus petroleum. SHF has a different seal swell than OHT but is ultimately sufficient to prevent leakage after equilibrium swell has been reached.

- The M1A1 system never showed visual seal leakage and/or seepage during the program. Again, this may be expected since the base fluids are similar, i.e., both are synthetic polyalphaolefin.

- Main gun drift was apparent in both test and control vehicles, although it was slightly more pronounced in the tanks filled with SHF. Satisfactory performance of other hydraulic fluid functions, i.e., wear, recoil recovery, turret rotation, etc., indicates probable acceptable field performance.

- For the period June 1993 through October 1994, the SHF test vehicles accumulated 5,327 miles, 1,491 hours, and fired 2,508 rounds of ammunition. The control vehicles accumulated 4,522 miles, 1,152 hours, and fired 1,966 rounds of ammunition. During this period of performance, back-to-back testing did not indicate any problems in terms of performance or wear. Field visits and discussions with crews in the field confirmed that no differences in performance could be identified.

VIII. RECOMMENDATIONS

While this report only summarizes the results obtained from field demonstrations concerning the use of SHF as a replacement for both petroleum-based and synthetic fluids, it is possible to provide the following recommendations:

1. Further vehicular performance testing should be conducted to document SHF performance at lower temperatures. While high ambient temperature testing may be more severe in some aspects, i.e., fluid viscosity lowering/seal seepage, low temperature performance is certainly a concern in the hydraulic systems.

2. Although the seal leaks and/or seepage that occurred in the M109 systems midway through the demonstration program turned out to be a self-healing problem, further research should be conducted to determine the mechanisms responsible for the seepage and subsequent self-correction observed in the M109.

3. The field demonstration conducted supports the recommendation that SHF can be a suitable replacement for MIL-H-46170 in the M1A1 systems and MIL-H-6083 in the M109 systems. However, users should be informed that the M109 systems, having first used MIL-H-6083 (petroleum base) for an extended period of time, **may** experience self-correcting seal seepage after conversion to the synthetic-based SHF.

4. Continued monitoring of the vehicles used in this demonstration may provide additional information. This monitoring would include field inspections and reviews of maintenance records.

IX. LIST OF REFERENCES

1. Military Specification MIL-H-46170B, "Hydraulic Fluid, Rust Inhibited, Fire Resistant, Synthetic Hydrocarbon Base," 31 March 1988.

2. Military Specification MIL-H-6083E, "Hydraulic Fluid, Petroleum Base, for Preservation and Operation," 14 August 1986.

3. Military Specification MIL-H-5606E, "Hydraulic Fluid, Petroleum Base; Aircraft, Missile, and Ordnance," 02 March 1984.

4. Wright, B.R., Alvarez, R.A., and Lacey, P.I., "Technology Demonstration of Single Hydraulic Fluid for Armored Ground Vehicle Systems," Interim Report BFLRF No. 298 (AD A280170), prepared by U.S. Army Belvoir Fuels and Lubricants Research Facility, San Antonio, Texas, December 1993.

5. American Society for Testing and Materials Method D 97-93, "Standard Test Method for Pour Point of Petroleum Products," ASTM, 1916 Race Street, Philadelphia, PA, 1993.

6. American Society for Testing and Materials Method D 445-94, "Standard Test Method for Kinematic Viscosity of Transparent and Opaque Liquids (the Calculation of Dynamic Viscosity)," ASTM, 1916 Race Street, Philadelphia, PA, 1994.

7. American Society for Testing and Materials Method D 664-89, "Standard Test Method for Acid Number of Petroleum Products by Potentiometric Titration," ASTM, 1916 Race Street, Philadelphia, PA, 1989.

8. American Society for Testing and Materials Method D 92-90, "Standard Test Method for Flash and Fire Points by Cleveland Open Cup," ASTM, 1916 Race Street, Philadelphia, PA, 1990.

9. American Society for Testing and Materials Method D 1744-92, "Standard Test Method for Determination of Water in Liquid Petroleum Products by Karl Fischer Reagent," ASTM, 1916 Race Street, Philadelphia, PA, 1992.

APPENDIX A

Military Vehicles and Equipment Using FRH, OHT, and OHA Fluids

TABLE A-1. Military Vehicles and Equipment Using FRH

National Stock No.	Lubrication Order No.	Nomenclature
2350-01-110-4660	9-2350-267-12	Carrier Ammunition M992
2350-01-068-4089	9-2350-261-12	Carrier Command Post M577A2
2350-01-091-5405	9-1450-646-12	Carrier Multiple Launch Rocket System
2350-01-069-6931	9-2350-261-12	Carrier Mortar 107mm M106A2
2350-01-068-4077	9-2350-261-12	Carrier Personnel M113A2
2350-01-219-7577	9-2350-277-12	Carrier Personnel M113A3
2350-01-203-0188	9-2350-261-12	Carrier Smoke Generator M1059
2350-00-795-1797	9-2350-222-12	Combat Engineer Vehicle M728
2350-01-103-5641	9-2350-259-12	Combat Vehicle ITV M901A1
2350-01-179-1027	9-2350-252-12	Infantry Fighting Vehicle M2A1
2320-01-248-7619	9-2350-284-12	Infantry Fighting Vehicle M2A2
1905-01-284-2647	55-1905-222-12	Landing Craft Mechanized LCM8
1905-01-284-2648	55-1905-222-12	Landing Craft Mechanized LCM8
1905-01-154-1191	55-1905-223-12	Landing Craft Utility LCU
1905-00-168-5764	55-1905-219-12	Landing Craft Utility LCU1667-1670
1905-01-009-1056	55-1905-220-12	Landing Craft Utility LCU1671-1679
2305-01-061-6230	55-2305-001-12	Lighter Air Cushion Vehicle 30-ton
2350-01-061-2445	9-2350-255-12	Tank Combat Full Tracked M1
2350-00-582-5595	9-2350-258-12	Tank Combat Full Tracked M48A5
2350-00-930-3590	9-2350-232-12	Tank Combat Full Tracked M60A2

TABLE A-2. Military Vehicles and Equipment Using OHT

National Stock No.	Lubrication Order No.	Nomenclature
2350-00-808-7100	5-2350-262-12	Armored Combat Earthmover ACE M9
2350-00-873-5408	9-2350-230-12	Armored Recon ABN Assault Vehicle M551A1
5420-00-889-2020	5-5420-202-12	Bridge Launcher Armored Vehicle M60
2350-01-110-4660	9-2350-267-12	Carrier Ammunition M992
2350-01-085-3792	9-2350-266-12	Carrier Personnel Fire Spt M981
2350-01-103-5641	9-2350-259-12	Combat Vehicle ITV M901A1
3930-00-790-2175	5-3910-202-12	Conveyor Belt Mdl PG70
3810-00-861-8088	5-3810-288-12	Crane Shovel 20-ton M320T
2350-01-017-2113	9-2350-300-12	Gun Air Defense Arty M163A1
3895-00-014-8583	5-3895-265-12	Hammer Pile Driver Mdl SLE
3895-00-443-4696	5-3895-332-12	Hammer Pile Driver MKT DA35
1015-00-086-8164	9-1015-234-12	Howitzer Light Towed M102
2350-01-031-0586	9-2350-311-12	Howitzer Medium SP M109A2
2350-01-041-4590	9-2350-304-12	Howitzer SP 8in M110A2
6675-01-105-5753	5-6675-315-12	Topographic Support System Distribution Section
3610-01-105-6422	5-3610-252-12	Topographic Support System Finishing Section
3610-01-105-6423	5-3610-253-12	Topographic Support System Paper Conditioning
2420-00-567-0135	5-2420-222-12	Tractor Wheeled JD410
2320-01-113-3636	9-2320-281-12	Truck Chassis Topographic Support System

TABLE A-3. Military Vehicles and Equipment Using OHA

National Stock No.	Lubrication Order No.	Nomenclature
2350-01-068-4089	9-2350-261-12	Carrier Command Post M577A2
2350-01-069-6931	9-2350-261-12	Carrier Mortar M106A2
2350-01-068-4077	9-2350-261-12	Carrier Personnel M113A2
2350-01-085-3792	9-2350-266-12	Carrier Personnel Fire Support M981
2350-01-203-0188	9-2350-261-12	Carrier Smoke Generator M1059
3810-00-542-4982	5-3810-207-12	Crane Shovel 20-ton Mdl M200
6115-00-118-1240	5-6115-465-12	Generator Set 30KW 60HZ MEP005A
6115-00-118-1248	5-6115-465-12	Generator Set 30KW 60HZ MEP114A
6115-00-475-6573	5-6115-274-12	Generator Set 45KW 400HZ Mdl 52300
6115-00-118-1243	5-6115-545-12	Generator Set 60KW 60HZ MEP006A
6115-00-118-1252	5-6115-545-12	Generator Set 60KW 60HZ MEP105A
6115-00-118-1253	5-6115-545-12	Generator Set 60KW 400HZ MEP115A
6115-00-133-9101	5-6115-457-12	Generator Set 100KW 60HZ MEP007A
6115-00-133-9102	5-6115-457-12	Generator Set 100KW 60HZ MEP106A
6115-00-133-9104	5-6115-458-12	Generator Set 200KW 60HZ MEP009A
6115-00-935-8729	5-6115-458-12	Generator Set 200KW 60HZ MEP108A
6115-00-999-7901	5-6115-400-12	Generator Set 200KW 60HZ SF-200-MD/CIED
1005-01-177-9237	9-1005-318-13	Gun Air Defense Towed M167A2
3825-00-810-7074	5-3825-213-12	Snow Removal Unit S-349B
3930-00-621-7413	10-3930-225-12	Truck FL 15000lbs MHE175
2320-01-121-2102	9-2320-285-12	Truck Tractor Yard Type M878A1

APPENDIX B

Single Hydraulic Fluid Pilot Field Demonstration Plan for Ft. Bliss, Texas

SINGLE HYDRAULIC FLUID
PILOT FIELD DEMONSTRATION PLAN
FOR
FT. BLISS, TEXAS

I. Purpose

The purpose of this plan is to demonstrate acceptable field performance of combat tracked vehicles using the new single hydraulic fluid (SHF) that was developed to replace MIL-H-6083 and MIL-H-46170 fluids. SHF has better flammability properties than MIL-H-6083 and will perform better at low temperatures than MIL-H-46170.

II. Objective

The objective is to measure the performance of SHF relative to the performance of petroleum-based MIL-H-6083 and synthetic-based MIL-H-46170 fire resistant hydraulic fluids. The performance will be measured in the hydraulic systems of tracked combat vehicles by monitoring the following:

- Selected test vehicles operating on SHF and selected control vehicles operating on conventional hydraulic fluid;

- Hours of operation of both test and control vehicles;

- Results of periodic hydraulic fluid sampling and analysis;

- System performance inspections as specified in applicable technical manuals.

III. Scope

A pilot normal mission/training nonimpact field evaluation to demonstrate the acceptability of a newly developed single hydraulic fluid will be conducted at Ft. Bliss, Texas, on the following types of vehicles:

- M1A1 Main Battle Tank
- M109A2 Self-Propelled Howitzer

The U.S. Army 3rd Armored Cavalry Regiment (ACR) has agreed to support field evaluations of the newly developed single hydraulic fluid. Point of contact is CPT Virgil Williams, Regimental Maintenance Management Officer, Ft. Bliss, Texas, 79916-5000, Telephone: Autovon 784-6400, Commercial (915) 568-6400.

The U.S. Army TARDEC, Mobility Technology Center-Belvoir (MTCB) has overall program responsibility. Point of contact is Mr. M.E. LePera, Chief, Fuels and Lubricants Division, Logistics Equipment Directorate, Ft. Belvoir, Virginia, 22060-5843, Telephone: Autovon 354-3435, Commercial (703) 704-1819.

The U.S. Army TARDEC Fuels and Lubricants Research Facility (TFLRF) at Southwest Research Institute (SwRI) will conduct the field evaluation and will furnish the necessary test equipment and the test single hydraulic fluid. Point of contact is Mr. Ruben Alvarez, U.S. Army TARDEC Fuels and Lubricants Research Facility, Southwest Research Institute, P.O. Drawer 28510, San Antonio, Texas, 78228-0510, Telephone: Commercial (210) 522-3264.

The Deputy Director for Logistics, Directorate of Installation Support (ATZC-ISL) and the U.S. Army Materiel Command Logistics Assistance Office (AMXLA-C-C-BL) at Ft. Bliss, Texas, will be notified of omissions or additions in the scope of the field demonstration plan. Copies of correspondence, interim, and final reports will be provided to these activities.

IV. Responsibilities

A. 3rd ACR

Responsibilities of the 3rd ACR are as follows:

- Furnish task units that will provide the test and control vehicles and crews;
- Arrange coordination meetings between TFLRF staff and participating units.

The following vehicles are required for the demonstration:

Vehicle	Quantity	Hydraulic Fluid
M1A1	6	SHF
M1A1	6	MIL-H-46170
M109A2	6	SHF
M109A2	6	MIL-H-6083

B. TFLRF

Responsibilities of TFLRF are as follows:

- Provide technical support personnel to conduct the evaluations;
- Provide analytical equipment for chemical analysis;
- Provide test fluid to participating units;
- Coordinate shipment and storage of test fluid at Ft. Bliss;
- Prepare interim and final reports.

V. Period of Evaluation

The evaluation will be conducted for a minimum of one year.

VI. Procedure

A. Test Vehicle Preparation

1. The hydraulic systems of vehicles selected for evaluation, test and control, must be inspected to ensure that systems are fully operational.

2. The hydraulic systems of test and control vehicles will be drained, flushed, and filled with the appropriate hydraulic fluid as prescribed in applicable lubrication orders.

B. Data Requirements

TFLRF personnel will visit participating units on a quarterly basis to collect data and discuss problems, if any, with maintenance personnel and crews. The participating unit's point of contact will be notified prior to each visit. Data forms will be provided by TFLRF. The data will include but are not limited to the following:

1. Hours of operation;

2. Changes or additions of hydraulic fluid;

3. Hydraulic system malfunction, response, seal leakage, binding, etc.

Quarterly hydraulic fluid samples will be obtained by TFLRF personnel. Prior to withdrawing the samples, the system will be exercised for 15 minutes to allow the fluid to warm and to ensure a homogenous sample for analysis. The fluid level will be replenished to the normal "full" mark **after** sampling.

APPENDIX C

Single Hydraulic Fluid Field Evaluation Directive

DEPARTMENT OF THE ARMY
HEADQUARTERS, THIRD ARMORED CAVALRY REGIMENT
FORT BLISS, TEXAS 79916

AFVF

25 February 1993

MEMORANDUM FOR 1/3 and 2/3 Executive Officers

SUBJECT: Single Hydraulic Fluid Evaluation

1. Your Squadron has been selected to participate in a non-impact field evaluation on the acceptability of a newly developed single hydraulic fluid. This evaluation will take place in mid April. The POC for each Squadron will be the Squadron Maintenance Officer or Squadron Maintenance Tech.

2. The following vehicles are required from each Squadron:

VEHICLES	QUANTITY
M1A1	6
M3A2	6
M109A2	6

3. More detailed information concerning this evaluation is attached. Let me reiterate, this is a non-impact evaluation.

4. POC is CPT(P) Williams, 3-6400/1870.

GERALD S. DALZELL
LTC, AR
RXO

APPENDIX D

Letter Report 93-4, Entitled "Laboratory Evaluation of Industry Candidate Single Hydraulic Fluids"

DEPARTMENT OF THE ARMY
HEADQUARTERS, US ARMY AVIATION AND TROOP COMMAND
BELVOIR RESEARCH, DEVELOPMENT AND ENGINEERING CENTER
FORT BELVOIR, VIRGINIA 22060-5606

REPLY TO
ATTENTION OF

13 August 1993

LETTER REPORT 93 - 4

SUBJECT: Laboratory Evaluation of Industry Candidate Single Hydraulic Fluid

1. **BACKGROUND:** The Army is currently dependent upon three military specification hydraulic fluids (MIL-H-5606, OHA; MIL-H-6083, OHT; MIL-H-46170, FRH) for ground vehicles and a fourth hydraulic fluid for aircraft (MIL-H-83282 in addition to MIL-H-5606, and MIL-H-6083). In an attempt to reduce the logistic burden implied by the use of four different fluids, efforts have been aimed at developing a single fluid that provides the same performance as the current fluids. The first step in such an endeavor was to determine the fluid performance requirements that would be acceptable for use in all ground equipment and aircraft. After identifying performance targets, work was performed to develop candidate formulations that would prove or disprove the viability of these requirements. Efforts by the Belvoir Research, Development, and Engineering Center (BRDEC) Fuels and Lubricants Division revealed that the proposed target requirements could in fact be met. These requirements were passed on to industry so that they could formulate their own candidates for Single Hydraulic Fluid (SHF).

2. **OBJECTIVE:** Evaluate industry candidate fluid formulations against the target performance requirements for Single Hydraulic Fluid to determine if a reliable source of supply will be available.

3. **APPROACH:** In order to simplify the transition from four fluids to one, the basic chemistry of FRH was retained. This approach would allow for compatibility with existing systems and fluids, and require only a "flush and fill" changeover. It would also provide the desired fire protection. The only other requirements of the new fluid would be increased seal swell and low viscosities at low temperatures. Table 1 summarizes all SHF performance requirements and illustrates how they compare to MIL-H-46170 (FRH).

TABLE 1
COMPARISON OF PERFORMANCE REQUIREMENTS

PERFORMANCE TEST	MIL-L-46170	SHF
Oxidation/Corrosion ASTM D4636, #3	168 hrs @ 135°C	168 hrs @ 135°C
Corrosion Inhibition ASTM D1748	100 hrs	100 hrs
Galvanic Corrosion FTM 5322	10 days	10 days
Low Temp Stability FTM 3458	72 hrs @ -54°C	72 hrs @ -54°C
Pour Point ASTM D97	-60°C	-60°C
Viscosity @ 40°C ASTM D445	19.5 cSt max	19.5 cSt max
Viscosity @ 100°C ASTM D445	3.4 cSt min	2.5 cSt min
Viscosity @ -40°C ASTM D445	2600 cSt max	800 cSt max
Viscosity @ -54°C ASTM D445	report	3500 cSt max
Solid particle Count MIL-H-46170	10,000 max @ 5-25 micrometers	10,000 max @ 5-15 micrometers
Solid Particle Count MIL-H-46170	250 max @ 26-50 micrometers	1,000 max @ 16-25 micrometers
Solid Particle Count MIL-H-46170	50 max @ 51-100 micrometers	150 max @ 26-50 micrometers
Solid Particle Count MIL-H-46170	10 max @ over 100 micrometers	20 max @ 51-100 micrometers
Solid Particle Count MIL-H-46170		5 max @ over 100 micrometers
Acid Number ASTM D664	0.2 gm KOH/gm max	0.3 gm KOH/gm max

PERFORMANCE TEST	MIL-L-46170	SHF
Elastomer Swell FTM 3603	15% - 25%	19% - 30%
Evaporation Loss ASTM D972	5 % max	35% max
Steel on Steel Wear ASTM D4172	0.3 mm max @ 10 kg load	0.3 mm max @ 10 kg load
Steel on Steel Wear ASTM D4172	0.65 mm max @40 kg load	0.65 mm max @40 kg load
Foam Characteristics ASTM D892	65 ml max	65 ml max
Water Content ASTM D1744	500 ppm max	100 ppm max
Flash Point ASTM D92	219°C min	180°min
Fire Point ASTM D92	246° min	190°C min
Autoignition Temp ASTM E659	343°C min	325°C min
Hi Temp/Hi Press Ignt FTM 6052	no continuation of burning when ignition source is removed	no continuation of burning when ignition source is removed
Flame Propagation MIL-H-83282	0.3 cm/sec max	0.3 cm/sec max
Storage Stability FTM 3465	12 months	12 months

TABLE 1 (continued)

There are several significant differences between FRH and SHF. The most important changes are in the viscosities and fire and flash points. The higher temperature viscosity (i.e., 3.4 cSt at 100°C) has been lowered to 2.5 cSt for SHF. Laboratory wear tests indicate that this difference in viscosity does not diminish the wear protection of SHF. The low temperature viscosities for SHF have been changed to reflect the viscosity requirements for OHT. While the flash points and fire points for SHF have been lowered compared to FRH, previous testing of similar fluid

formulations indicate all other fire resistance characteristics remain the same, thus the fire resistance of SHF is truly comparable to FRH.

With the finalization of these target values, industry candidate fluids were accepted for evaluation against the performance requirements. Five candidates have been evaluated thus far. While all formulations consist of polyalphaolefin/ester combinations, the additive packages vary widely.

4. **RESULTS:** All candidate formulations were subjected to the same tests as indicated in Table 1 with the exception of particle count, acid number, and flammability testing (last four tests listed in table). The flammability tests will be conducted by the Belvoir Fuels and Lubricants Research Facility with results to be summarized in a separate report. The acid numbers and particle count were not tested at BRDEC, but were found to be satisfactory as submitted by the manufacturers or independent labs. Test results of the industry candidate fluids follow.

FLASH POINT/FIRE POINT...The Flash Points and Fire Points for Candidates A - E are listed in the Table 2. All candidates passed the minimum temperature requirement of 180° C for Flash point with the exception of Candidate D which exhibited a slightly lower flash point of 178 °C. The highest flash point of 187°C was achieved by Candidate B. All five candidates passed the minimum temperature requirement of 190° C for Fire Point with a range of 191 - 198° C with Candidates A and E exhibiting the temperature of 198° C.

TABLE 2
FLASH POINTS/FIRE POINTS

FLUID	FLASH POINT °C	FIRE POINT °C
Candidate A	185	198
Candidate B	187	197
Candidate C	184	194
Candidate D	178	191
Candidate E	182	198

VISCOSITY...Test results for candidates A-E are shown in Table 3. All candidate fluids passed the requirements for viscosity at temperatures of 40°, 100°, -40° and -54° C. All candidates are well below the maximum viscosity at 40° C but very close

to the minimum requirement at 100° C.

TABLE 3
VISCOSITY

FLUID	@ 40 °C (cSt)	@ 100 °C (cSt)	@ -40 °C (cSt)	@ -54 °C (cSt)
Candidate A	9.58	2.64	756	3440
Candidate B	9.31	2.63	753	3407
Candidate C	9.31	2.63	755	3440
Candidate D	9.05	2.57	720	3272
Candidate E	9.61	2.68	754	3390

WEAR RESISTANCE...Results of 4 Ball Wear Tests at 10kg and 40kg loads are summarized in Table 4. Not all test results were obtained for all fluids due to insufficient volume of test fluid. Data from manufacturers or independent laboratories indicate that each of the fluids passes the criteria for wear protection at both loads. Test results generated by BRDEC also indicate compliance with the wear protection requirements by these fluids.

TABLE 4
STEEL ON STEEL WEAR

Fluid	@ 10kg (mm)	@ 40kg (mm)
Candidate A	-	0.54
Candidate B	-	-
Candidate C	0.27	0.65
Candidate D	0.30	0.48
Candidate E	0.29	0.65

FOAMING CHARACTERISTICS...The tendency of oils to foam can present serious problems in systems with high-speed gearing, or high-volume pumping. Excessive foaming can cause inadequate lubrication and/or overflow loss of the lubricant which may lead to mechanical failure. The results of the Foaming Characteristics test for Candidates A - E are listed in Table 5. All of the candidate fluids passed in each sequence of the test. The first number indicates the maximum volume of foam recorded after the aeration period and the second number indicates the amount of foam remaining at the end of the settling period.

TABLE 5
FOAMING CHARACTERISTICS

FLUID	SEQUENCE I (ml)	SEQUENCE II (ml)	SEQUENCE III (ml)
Candidate A	40-0	20-0	25-0
Candidate B	10-0	30-0	60-0
Candidate C	30-0	30-0	10-0
Candidate D	40-0	30-0	30-0
Candidate E	5-0	30-0	5-0

PHYSICAL CHARACTERIZATION...Evaporation Loss, Water Content and Pour Point are listed in Table 6 for each candidate fluid. Each fluid passed the requirement for the Evaporation Loss test with a range of 28.37 - 33.75 % . In order to check the fluid's tendency to absorb water, Moisture Contents were determined for each candidate fluid several months after it had been opened and in use. Water Contents ranged from 152.7 to 470.1 ppm, which is within the established maximum limit of 500 ppm for MIL-H-46170. In that the water content of the candidate fluids fell well into preestablished limits after a significant amount of exposure to the atmosphere, absorption of water is not believed to be a problem. The Pour Point of an oil gives an index of the lowest temperature of utility for that oil. All of the candidate fluids met the requirement of -60° C for the pour point. It should be noted, however, that all of the candidate fluids exhibited superior performance by still showing significant fluidity at -65° C. Due to the limitations of the test equipment, the point at which the candidate fluids ceased to move could not be established below -65° C.

TABLE 6
EVAPORATION LOSS - WATER CONTENT - POUR POINT

FLUID	EVAPORATION LOSS (%)	WATER CONTENT (ppm)	POUR POINT (°C)
Candidate A	33.75	470.1	below -60
Candidate B	33.70	290.1	below -60
Candidate C	33.35	396.8	below -60
Candidate D	32.15	152.7	below -60
Candidate E	28.37	358.9	below -60

COMPATIBILITY/STABILITY...Results of the Compatibility and Low Temperature Stability tests are listed in Table 7. There were no signs of instability or incompatibility in the form of gelling, separation, crystallization or sedimentation in any of the candidate fluids. All of the candidate fluids passed these two tests.

TABLE 7
COMPATIBILITY - LOW TEMPERATURE STABILITY

FLUID	COMPATIBILITY	LOW TEMPERATURE STABILITY
Candidate A	passed	passed
Candidate B	passed	passed
Candidate C	passed	passed
Candidate D	passed	passed
Candidate E	passed	passed

CORROSION PREVENTION...Galvanic Corrosion and Rust Protection test results are shown in Table 8. The Galvanic Corrosion test is used to determine the corrosive effect of an oil on a bimetallic couple. All of the candidate fluids passed this test by showing no signs of corrosion in the form of pitting, etching or discoloration on the steel disk. The Rust Protection test is used for measuring the relative abilities of metal preservatives to prevent corrosion of polished and sandblasted steel panels under

conditions of high humidity and temperature. The candidate fluids all passed this test by exhibiting no rust spots on the test surfaces of the panels after 100 hours.

TABLE 8
GALVANIC CORROSION RESISTANCE - RUST PROTECTION

FLUID	GALVANIC CORROSION RESISTANCE	RUST PROTECTION
Candidate A	passed	passed
Candidate B	passed	passed
Candidate C	passed	passed
Candidate D	passed	passed
Candidate E	passed	passed

OXIDATION/CORROSION STABILITY...The results of duplicate trials (sample #1 and sample #2) of the Corrosiveness and Oxidation Stability tests are listed in Table 9. This test provides a measure of the fluid's oxidation stability under high temperatures and its level of corrosion protection for aluminum, magnesium, cadmium, steel, and copper. Corrosion prevention is measured by the change in weight of metal coupons and by the appearance of discoloration and pitting on the coupons. The oxidation stability is measured by a change in viscosity of the fluid at 40° C, with a maximum allowable change of 10%. All of the candidate fluids passed all test criteria, although Candidate C showed a significant disparity in viscosity change for the duplicate trials.

TABLE 9
OXIDATION/CORROSION STABILITY

Fluid	Δ METAL WEIGHT (mg/cm^2)					Δ VISCOSITY (%)
	Cu	Al	Mg	Fe	Cd	
Candidate A Sample #1 Sample #2	 -0- .016	 .024 .008	 .032 -0-	 .056 .008	 .008 .248	 0.44 4.80

Candidate B Sample #1 Sample #2	.016 .024	.032 .056	-0- -0-	.016 .016	.008 .008	3.61 2.08
Candidate C Sample #1 Sample #2	.032 .016	.040 .032	.048 .032	.080 .064	.024 .032	0.43 9.70
Candidate D Sample #1 Sample #2	.048 .024	.040 .008	-0- .008	.008 .016	.024 .032	1.65 0.12
Candidate E Sample #1 Sample #2	.016 .008	.016 .016	-0- .032	.008 .032	.096 .144	1.5 1.5

TABLE 9 (continued)

5. **SUMMARY AND CONCLUSIONS:** All five candidates were found to exhibit satisfactory performance with the exception of Candidate D in the flash point. While the fluid tested low at BRDEC, independent testing indicates the fluid does meet the 180°C minimum. This fluid would technically be eligible for qualification against the performance requirements for SHF. All other test results were well within specified limits, indicating that industry could easily supply the Army with its desired Single Hydraulic Fluid. Since the additives for the different formulations vary so widely, the fluids were tested against each other and qualified formulations of FRH, and OHT. All fluids were found to be compatible at both high and low temperatures. Two of these candidate fluids are currently being tested in pump tests, gun recoil testing, and extended field testing in Abrams Tanks, Bradley Fighting Vehicles, and M109 Self Propelled Howitzers.

Ellen M. Purdy

Ellen M. Purdy
Chemical Engineer
Fuels and Lubricants Division

APPENDIX E

Used Hydraulic Fluid Analyses Results

TABLE E-1. 1st and 2nd Squadron M1A1 Abrams Tank Test Vehicles Before and After Test Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt			Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
		40°C	100°C	–40°C				
MIL-H-46170 Requirements	–54 min.	19.5 max.	3.4 min.	2600 max.	0.20 max.	204 min.	246 max.	0.05 max.
Before Demonstration Changeover to SHF								
D/1-14	–56	15.90	3.75	2533	0.13	227	246	0.05
D/1-24	–56	15.81	3.85	2515	0.11	221	254	0.05
D/1-34	–56	15.84	3.74	2518	0.11	227	252	0.05
H/2-13	–54	15.71	3.73	2439	0.11	224	248	0.05
H/2-23	–54	14.89	3.60	2187	0.10	224	248	0.03
H/2-33	–54	15.78	2.76	2458	0.12	229	252	0.05
After Demonstration Changeover to MIL-H-46170								
D/1-14	<–54	14.16	3.50	1932	0.12	216	238	0.02
D/1-24	<–54	12.60	3.25	1483	0.12	202	216	0.03
D/1-34	<–54	12.20	3.17	1383	0.13	196	218	0.03
H/2-13	<–54	12.31	3.20	1444	0.12	202	221	0.03
H/2-23	<–54	12.40	3.21	1426	0.12	202	218	0.02
H/2-33	<–54	12.36	3.21	1411	0.12	196	221	0.03

TABLE E-2. 1st and 2nd Squadron M109A2 Howitzer Test Vehicles Before and After Test Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt			Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
		40°C	100°C	–40°C				
MIL-H-6083 Requirements	–59 min.	13 min.	NR*	800 max.	0.20 max.	82 min.	NR	0.05 max.
Before Demonstration Changeover to SHF								
How/1-11	–58	13.74	4.76	601	0.13	104	113	0.06
How/1-12	–57	13.75	4.86	569	0.14	110	116	0.10
How/1-13	–57	13.92	4.67	769	0.13	113	118	0.03
How/2-12	N/A†	N/A	N/A	N/A	N/A	N/A	N/A	N/A
How/2-15	–50	13.65	4.81	573	0.07	108	116	0.02
How/2-16	–50	13.35	4.47	758	0.07	111	116	0.02
After Demonstration Changeover to MIL-H-6083								
How/1-11	<–54	12.86	4.51	586	0.12	110	113	0.02
How/1-12	<–54	12.87	4.50	586	0.12	110	116	0.02
How/1-13	<–54	13.01	4.57	580	0.11	107	116	0.02
How/2-12	<–54	12.96	4.55	575	0.12	104	116	0.03
How/2-15	<–54	12.51	4.35	583	0.13	107	113	0.05
How/2-16	<–54	13.04	4.52	621	0.13	104	113	0.05

* NR = Not required
† N/A = Not available for testing

TABLE E-3. 1st Squadron M109A2 Howitzer Test Vehicles After Changeover Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt			Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
		40°C	100°C	–40°C				
SHF Proposed Requirements	–60 min.	8 min.	2.5 min.	800 max.	Report	180 min.	190 min.	0.01 max.
How-11 SN 4910								
Initial Sampling	–57	9.45	2.72	731	0.19	166	188	0.02
1st Quarter	<–54	9.64	2.83	731	0.27	152	174	0.03
2nd Quarter	<–54	9.51	2.78	723	0.27	160	177	0.03
3rd Quarter	<–54	9.53	2.79	720	0.26	168	174	0.03
4th Quarter	<–54	9.61	2.75	773	0.27	171	191	0.04
Average	<–54	9.55	2.77	736	0.25	163	181	0.03
How-12 SN 4887								
Initial Sampling	–57	9.40	2.71	734	0.22	174	193	0.02
1st Quarter	<–54	9.55	2.38	725	0.27	166	177	0.04
2nd Quarter	<–54	9.54	2.79	716	0.24	157	171	0.04
3rd Quarter	<–54	9.53	2.80	708	0.25	163	174	0.03
4th Quarter	<–54	9.52	2.79	730	0.27	160	174	0.04
Average	<–54	9.51	2.69	723	0.25	164	178	0.03
How-13 SN 2895								
Initial Sampling	–57	9.43	2.71	744	0.19	177	193	0.02
1st Quarter	<–54	9.57	2.77	747	0.27	163	182	0.01
2nd Quarter	<–54	9.38	2.72	731	0.24	171	188	0.03
3rd Quarter	<–54	9.40	2.73	725	0.24	168	182	0.02
4th Quarter	<–54	9.41	2.72	741	0.27	168	188	0.04
Average	<–54	9.44	2.73	738	0.24	169	187	0.02

TABLE E-4. 2nd Squadron M109A2 Howitzer Test Vehicles After Changeover Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt			Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
		40°C	100°C	–40°C				
SHF Proposed Requirements	–60 min.	8 min.	2.5 min.	800 max.	Report	180 min.	190 min.	0.01 max.
How-12 SN 5324								
Initial Sampling	–54	9.37	2.73	718	0.42	183	191	0.02
1st Quarter	<–54	9.40	2.73	734	0.33	174	188	0.03
2nd Quarter	<–54	9.79	2.79	794	0.29	177	188	0.06
3rd Quarter	<–54	9.40	2.69	738	0.28	188	199	0.03
4th Quarter	<–54	9.40	2.68	744	0.26	182	193	0.07
How-15 SN 2893								
Initial Sampling	–54	9.46	2.74	723	0.42	169	177	0.02
1st Quarter	<–54	9.54	2.80	728	0.35	160	171	0.03
2nd Quarter	<–54	9.53	2.80	711	0.27	166	174	0.05
3rd Quarter	<–54	9.53	2.81	710	0.25	154	171	0.03
4th Quarter	<–54	9.56	2.80	718	0.26	160	171	0.07
How-16 SN 2132								
Initial Sampling	–47	9.42	2.72	733	0.37	172	191	0.02
1st Quarter	<–54	9.34	2.70	742	0.22	171	188	0.03
2nd Quarter	ND*	11.62	3.07	729	0.19	191	212	0.25
3rd Quarter	<–54	11.41	3.05	1152	0.17	191	207	0.22
4th Quarter	<–54	11.15	2.99	1100	0.18	191	204	0.13

* ND = Not determined

TABLE E-5. 1st and 2nd Squadron M109A2 Howitzer Control Vehicles Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt 40°C	Viscosity, D 445, cSt 100°C	Viscosity, D 445, cSt –40°C	Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
MIL-H-6083 Requirements	–59 min.	13 min.	NR*	800 max.	0.20	82 min.	NR	0.05 max.
How/1-15 SN 4907								
Initial Sampling	–57	14.23	5.05	574	0.14	104	116	0.05
1st Quarter	<–54	13.82	4.96	551	0.13	99	104	0.03
2nd Quarter	<–54	13.86	4.95	541	0.11	104	110	0.04
3rd Quarter	<–54	13.96	5.01	549	0.13	107	110	0.03
4th Quarter	<–54	13.97	5.00	549	0.12	102	116	0.03
How/1-16 SN 2899								
Initial Sampling	–57	14.23	5.05	574	0.14	104	113	0.05
1st Quarter	<–54	13.59	4.85	560	0.12	102	113	0.02
2nd Quarter	<–54	13.54	4.83	539	0.09	104	116	0.02
3rd Quarter	<–54	13.63	4.88	540	0.12	104	121	0.03
4th Quarter	<–54	13.75	4.91	559	0.12	104	116	0.03
How/2-13 SN 5030								
Initial Sampling	–54	13.37	4.51	726	0.13	107	124	0.05
1st Quarter	<–54	13.52	4.55	745	0.52	104	124	0.03
2nd Quarter	<–54	13.41	4.55	734	0.09	113	121	0.05
3rd Quarter	<–54	13.51	4.62	703	0.11	107	121	0.02
4th Quarter	N/A†	N/A	N/A	N/A	N/A	N/A	N/A	N/A

* NR = Not required
† N/A = Not available for testing

TABLE E-6. 1st Squadron M1A1 Abrams Tank Test Vehicles After Changeover Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt			Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
		40°C	100°C	–40°C				
SHF Proposed Requirements	–60 min.	8 min.	2.5 min.	800 max.	Report	180 min.	190 min.	0.01 max.
D-14 SN L13071								
Initial Sampling	–56	9.96	2.76	867	0.25	191	204	0.02
1st Quarter	<–54	10.09	2.81	891	0.35	191	199	0.01
2nd Quarter	<–54	10.06	2.84	878	0.23	191	202	0.02
3rd Quarter	<–54	10.07	2.81	872	0.26	188	199	0.05
4th Quarter	N/A*	N/A	N/A	N/A	N/A	N/A	N/A	N/A
D-24 SN L13045								
Initial Sampling	–59	9.83	2.83	847	0.28	185	202	0.02
1st Quarter	<–54	9.96	2.79	883	0.30	180	202	0.02
2nd Quarter	<–54	9.97	2.78	866	0.24	191	204	0.02
3rd Quarter	<–54	9.95	2.79	858	0.23	185	202	0.03
4th Quarter	<–54	9.94	2.78	867	0.27	191	204	0.03
D-34 SN L13073								
Initial Sampling	–57	9.96	2.77	874	0.25	182	202	0.02
1st Quarter	<–54	9.22	2.67	758	0.27	182	193	0.02
2nd Quarter	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3rd Quarter	<–54	9.20	2.65	723	0.30	185	202	0.03
4th Quarter	<–54	9.21	2.64	728	0.32	185	202	0.03

* N/A = Not available for testing

TABLE E-7. 2nd Squadron M1A1 Abrams Tank Test Vehicles After Changeover Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt			Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
		40°C	100°C	–40°C				
SHF Proposed Requirements	–60 min.	8 min.	2.5 min.	800 max.	Report	180 min.	190 min.	0.01 max.
H-13 SN L12523								
Initial Sampling	–47	9.80	2.75	830	0.30	186	199	0.01
1st Quarter	<–54	9.90	2.78	855	0.30	193	204	0.02
2nd Quarter	<–54	9.89	2.76	854	0.27	188	207	0.03
3rd Quarter	<–54	9.56	2.72	781	0.25	188	199	0.03
4th Quarter	<–54	9.56	2.71	783	0.27	185	196	0.03
H-23 SN L13011								
Initial Sampling	–54	9.83	2.75	836	0.34	188	202	0.02
1st Quarter	<–54	9.96	2.78	872	0.24	185	202	0.02
2nd Quarter	<–54	9.85	2.76	844	0.24	188	199	0.02
3rd Quarter	<–54	9.71	2.75	809	0.24	188	202	0.03
4th Quarter	<–54	9.69	2.74	810	0.27	185	202	0.03
H-33 SN L13021								
Initial Sampling	–54	9.88	2.77	849	0.34	183	205	0.02
1st Quarter	<–54	9.91	2.78	864	0.30	185	202	0.02
2nd Quarter	<–54	10.13	2.80	896	0.27	191	204	0.05
3rd Quarter	<–54	9.79	2.76	823	0.26	188	202	0.03
4th Quarter	<–54	9.81	2.75	832	0.27	185	202	0.03

TABLE E-8. 1st Squadron M1A1 Abrams Tank Control Vehicles Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt			Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
		40°C	100°C	–40°C				
MIL-H-46170 Requirements	–54 min.	19.5 max.	3.4 min.	2600 max.	0.20 max.	204 min.	246 max.	0.05 max.
D-12 SN L13062								
Initial Sampling	–56	15.81	3.74	2517	0.13	224	252	0.05
1st Quarter	<–54	15.82	3.77	2551	0.15	224	252	0.03
2nd Quarter	<–54	15.78	3.75	2458	0.13	224	249	0.04
3rd Quarter	<–54	15.78	3.77	2440	0.15	227	249	0.05
4th Quarter	<–54	15.81	3.76	2588	0.16	221	249	0.04
D-22 SN L13075								
Initial Sampling	–56	15.86	3.87	2553	0.14	224	252	0.05
1st Quarter	<–54	15.92	3.77	2547	0.15	229	246	0.04
2nd Quarter	N/A*	N/A	N/A	N/A	N/A	N/A	N/A	N/A
3rd Quarter	<–54	15.89	3.78	2481	0.15	227	252	0.04
4th Quarter	<–54	15.91	3.77	2499	0.16	221	249	0.04
D-32 SN L13037								
Initial Sampling	–56	15.85	3.75	2520	0.11	224	249	0.03
1st Quarter	<–54	15.44	3.75	2515	0.15	229	254	0.04
2nd Quarter	<–54	15.75	3.75	2474	0.12	224	249	0.09
3rd Quarter	<–54	15.78	3.76	2440	0.15	227	249	0.10
4th Quarter	<–54	15.77	3.74	2489	0.17	224	243	0.13

* N/A = Not available for testing

TABLE E-9. 2nd Squadron M1A1 Abrams Tank Control Vehicles Used Fluid Analyses Results

	Pour Point, D 97, °C	Viscosity, D 445, cSt 40°C	Viscosity, D 445, cSt 100°C	Viscosity, D 445, cSt –40°C	Acid Number, D 664, mg KOH/g	Flash Point, D 92, °C	Fire Point, D 92, °C	Water Content, D 1744, wt%
MIL-H-46170 Requirements	–54 min.	19.5 max.	3.4 min.	2600 max.	0.20 max.	204 min.	246 max.	0.05 max.
H-12 SN L12527								
Initial Sampling	<–54	15.11	3.62	2249	0.08	224	248	0.03
1st Quarter	<–54	15.11	3.67	2313	0.10	227	252	0.03
2nd Quarter	<–54	15.10	3.65	2257	0.09	227	246	0.03
3rd Quarter	N/A*	N/A	N/A	N/A	N/A	N/A	N/A	N/A
4th Quarter	<–54	14.67	3.58	2302	0.08	216	246	0.03
H-22 SN L13028								
Initial Sampling	<–54	15.78	3.71	2454	0.11	230	248	0.05
1st Quarter	<–54	15.74	3.75	2476	0.13	224	252	0.04
2nd Quarter	<–54	15.72	3.63	2210	0.08	227	249	0.03
3rd Quarter	<–54	14.59	3.59	2072	0.08	218	243	0.03
4th Quarter	<–54	14.59	3.57	2090	0.09	224	246	0.03
H-32 SN L13009								
Initial Sampling	<–54	15.71	3.74	2452	0.11	NES†	NES	0.06
1st Quarter	<–54	15.71	3.74	2453	0.12	227	249	0.03
2nd Quarter	<–54	15.72	3.72	2421	0.11	227	249	0.05
3rd Quarter	<–54	15.69	3.75	2393	0.13	221	249	0.03
4th Quarter	<–54	15.63	3.73	2403	0.14	216	249	0.05

* N/A = Not available for testing
† NES = Not enough sample

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